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Rigid-Body-Control Subsystem Sizing for an Earth Science Geostationary Platform

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Summary

One of NASA's newly proposed initiatives is Mission to Planet Earth. This program envisions both low Earth and geostationary orbiting spacecraft supporting instruments that will measure and monitor land, ocean, and atmospheric variables that are important to understanding Earth's global change mechanisms. In order to minimize the number of spacecraft required in geostationary orbit and to allow data correlation in space and time, large, multipurpose platforms have been proposed. Many of the onboard instruments that require very high resolutions require very large components, such as antennas or telescopes. As a result, the size of the supporting spacecraft and the effects of environmental- and spacecraft-induced disturbances are increased. The problem is compounded by the fact that these antennas, along with many other sensors and instruments, require very precise pointing that consequently increases the complexity of the pointing and control subsystem. This paper presents the rigid-body-pointing analysis done as part of a larger geostationary platform study.

To accommodate as many of the pointing requirements for the science instruments as possible, the specific goal of the analysis was to determine what degree of rigid-body pointing was possible for this platform concept. The objective was to obtain a pointing accuracy of 18 arcsec (0.005°) for the platform, while instruments requiring a pointing accuracy greater than 18 arcsec would be mounted on a vernier isolation and pointing platform.

The computer-aided engineering system called Space Systems Integrated Simulation (SPASIS) was used to perform the analysis. First, to better understand the effects of various environmental forces and torques on the platform, uncontrolled motion of the platform was examined. Next, two reaction wheel assemblies, the NASA Standard and the Hubble Space Telescope, were used to investigate the platform controllability. The results indicate that the spacecraft can theoretically be controlled to the required accuracy of 18 arcsec along each axis. Of the two reaction wheel assemblies, the Space Telescope reaction wheels provide the highest degree of pointing accuracy. Furthermore, since the Space Telescope reaction wheels do not become saturated for at least 2 days (an important factor, considering the mission limitation of two housekeeping periods per orbit), they have the lowest propellant requirement for desaturation for the period (a factor influencing spacecraft lifetime). Two different control law gain sets were also examined: small gains, designed merely to meet the pointing requirement of 18 arcsec, and tight gains, designed to provide a greater degree of pointing accuracy than the nominal small gains. The reaction wheels investigated all represent currently available technology.

Symbols and Acronyms

e	maximum allowed error, rad
I	principal moment of inertia, kg-m^2
I_{sp}	propellant specific impulse, sec
K_A	torque command attitude gains
K_R	torque command rate gains
CMG	control moment gyro
DOF	degree of freedom
OMV	orbital maneuvering vehicle
OTV	orbital transfer vehicle
PMR	passive microwave radiometer
RCS	reaction control system
RWA	reaction wheel assembly
SPASIS	Space Systems Integrated Simulation
$T_{\max}$	assumed maximum value of reaction wheel torque, N-m
ω	angular velocity, rad/sec

Introduction

NASA has been studying several geostationary spacecraft and platform concepts for Earth science missions such as Mission to Planet Earth (ref. 1). The Mission to Planet Earth infrastructure will consist of both low Earth orbiting and geostationary orbiting spacecraft supporting instruments that measure and monitor land, ocean, and atmospheric environmental variables that are important to understanding Earth's global change mechanisms. The goals of this science mission are unprecedented in terms of both the number of variables to be measured and the requirements for spatial and temporal resolution. These goals have a number of implications for the spacecraft and the instruments themselves. First, the spacecraft will likely be a platform carrying many multidisciplinary science sensors so that measurements can be correlated in space and time. Second, many of the instruments that require very high resolutions will require very large components, such as antennas or telescopes. This increases the size of the supporting spacecraft and, consequently, the effects of environmental- and spacecraft-induced disturbances. Third, because of the geostationary operating altitude of the platform, the high resolution requirements of these components will require that very precise spacecraft pointing be maintained in spite of the large spacecraft size, significant disturbance environment, and potential structural flexibility. These and other spacecraft design issues that stem from science objectives may require advanced-technology solutions.

In order to quantify the performance requirements of an Earth science geostationary platform, a straw-man set of instruments representative of Mission to Planet Earth objectives was selected (based upon studies done by the Lockheed Missiles and Space Co., Inc.) and is summarized in table 1. This list contains three instruments with pointing requirements of 1.1 arcsec (0.0003°) and several others with requirements less than 20 arcsec (0.0056°). Thus, the spacecraft must provide a very stable base, with good rigid-body control as well as flexible-body control and disturbance isolation for these payloads. However, the large dimensions needed to support many instruments and to provide them with adequate fields of view result in a platform with flexible components that may be susceptible to disturbances from on-board mechanical systems (e.g., articulating solar arrays and cryogenic coolers) or the science payloads themselves (e.g., scanning mirrors and antenna gimbals). Thus, analyses to quantify pointing performance had to be initiated.

The Langley Research Center (LaRC) has conducted a study of geostationary platform concepts that had as its overall goal the identification of technology development issues and opportunities. Thus, the study was directed toward large, second-generation platforms rather than the near-term concepts proposed for launch before the year 2000. This paper presents the rigid-body-pointing analysis done as part of the overall geostationary platform study. Flexible-body characteristics, which are the subject of another study, are not addressed in this paper. Other analyses done as part of the overall platform study, of which this pointing analysis is a part, include a detailed structural analysis, antenna radio frequency performance (refs. 2 and 3), spacecraft subsystems requirements and technology options (ref. 4), and launch packaging and assembly methods for this class of large platforms (ref. 5). The rigid-body-controls analysis described herein was intended to verify the viability of the selected concept in terms of its controllability and pointing performance. This paper describes the selected platform concept and its mass and area distribution model and presents the results of the rigid-body-pointing analyses performed.

Platform Model

Numerous geostationary platform configurations of various sizes have been proposed in recent years, but one configuration that meets the needs for this advanced technology assessment study is shown in figure 1 and is described in the 1987 "Geostationary Platform Bus Study for Earth Observation Sciences" by Ford Aerospace and Communications Corp. This configuration provides many of the attributes of interest. It is a large spacecraft with two large antennas requiring either assembly or deployment on orbit. The proposed complement of 18 science instruments presents difficult pointing requirements because of on-orbit disturbances and instrument interactions. The platform is sized to meet science requirements typical of the Mission to Planet Earth, but no rigid-body-controllability analysis had been conducted to evaluate the pointing performance as a basis for the advanced technology assessments. The analysis described in this paper provides such a controls study and uses the pointing requirements given in table 1.

The Ford study, being conceptual in nature, lacked configuration detail in some areas. To conduct the in-depth performance analyses, several design decisions were made that resulted in the LaRC configuration (derived from the Ford configuration geometry) shown in figure 2. The most obvious change was to the antenna designs, where the focal-length-to-diameter ratio was increased from less than 1.0 to about 1.5 to accommodate likely reflector scanning strategies. Other changes were also made to add structural detail to the truss, antenna attachments, and payload module.

The LaRC Geostationary Earth Science Platform configuration shown in figure 2 uses a 3-m box truss structure (to be assembled at a space station) acting as a strongback for all subsystems and for a payload complement of 18 instruments including 2 antennas (15.0-m-diameter and 7.5-m-diameter solid reflectors). This erectable truss provides a rigid and stable base to which the various components of the spacecraft are connected.

Attached to the second bay (counting from left to right) of the truss are the payload module, housekeeping module, and orbital transfer vehicle (OTV) and orbital maneuvering vehicle (OMV) interface structure, all of which interconnect to provide the most rigid single element of the spacecraft. This rigidity is necessary to transmit boost loads and to provide a dimensionally stable base for the instruments located in the payload module. The payload module contains numerous instruments, including those with the most stringent pointing requirements. Connecting the payload module to the truss is the housekeeping module, which contains the major subsystems of the spacecraft such as the power subsystem and the attitude control subsystem. The OTV-OMV interface structure attaches to the bottom of the housekeeping module and extends through the second bay of the truss to a standard OTV-OMV docking ring.

The 15.0-m and 7.5-m passive microwave reflectors (refs. 2 and 3) are the largest instruments on the platform and are the primary platform configuration drivers. Each uses offset-fed Cassegrain geometry, which makes use of "folded optics" to enhance the scanning performance of the radiometer. In this configuration, the large primary reflector focuses the radiation upon the smaller subreflector that, in turn, focuses the radiation upon the feed array. The scanning of the radiometers is accomplished by pivoting their subreflectors through the use of electromechanical actuators. Because of the high operating frequencies of these radiometers, each has a solid primary reflector; since the dominant environmental disturbance at geosynchronous altitude is solar radiation pressure, the disturbance torques due to these large filled areas can present a controllability problem for the spacecraft. For the purpose of reducing these torques, the 15.0-m radiometer has been placed nearer to the center of mass of the spacecraft, while the 7.5-m radiometer is farther from the center of mass.

The solar arrays are attached directly to the housekeeping module and also use deployable masts to place them at sufficient distances from the spacecraft so that they are not shadowed by the 15.0-m radiometer reflector. Several instruments are also located at the solar panels to take advantage of the fact that they are solar pointing. Each solar panel rotates in 0.007° steps every 1.6785 sec to remain solar pointing.

A simplified model, with equivalent mass properties, inertias, and projected areas, was used for the rigid-body-controls analysis to represent the spacecraft, antennas, and other instruments and is shown in figure 3.

Platform Pointing Requirements

In order to satisfy all the instrument pointing requirements on the platform, a hierarchical approach is incorporated into the design of the conceptual control system. The required instrument accuracies range from 360.0 arcsec (0.1°) to 1.1 arcsec (0.0003°). The large energy required to control the entire platform to an accuracy of 1.1 arcsec would not be practical for satisfying the mission requirements. Only 4 of the 18 total instruments require a pointing accuracy greater than 18 arcsec, and they are assumed to be mounted on a vernier isolation and pointing platform located atop the payload module. To accommodate the pointing requirements of the remaining 14 science instruments, the platform bus is to be controlled to an accuracy of 18 arcsec. The specific goal of this pointing analysis is to determine what control system components are required for attitude control of the selected geostationary platform configuration to meet the pointing requirement of 18 arcsec. The immense inertia of this platform (see table 2) presents a very difficult task in terms of meeting the small pointing requirements.

Study Approach

The degree of environmental disturbances and the principal axes most affected by them were estimated for a spacecraft without a control system so that the proper control system (hardware and control laws) and placement of control devices could be determined.

After determining the uncontrolled motion of the spacecraft, a type of control device had to be chosen that would control the vehicle to the desired degree of accuracy. In choosing an attitude control device for the geostationary platform, several mission parameters were considered. First, at geostationary altitude, the Earth's magnetic field is too weak to consider the use of magnetic torquers, and RCS jets are not capable of providing the fine degree of pointing accuracy required. Additionally, RCS jets are used minimally as the primary controlling device (only for desaturation). Both CMG's and reaction wheels provide momentum control, but reaction wheels are generally less massive and provide lower torque values than CMG's, which are generally used for very large control applications. (See table 3.) Besides being one of the most often applied control devices in the aerospace community, reaction wheels do not depend upon the Earth's magnetic field and are relatively simple and light.

There are many types of reaction wheel assemblies (RWA's) currently available that cover a wide range of applications. For this analysis, two types of RWA's (ref. 6) were chosen for investigation: the NASA Standard RWA for midrange angular momentum applications and the Space Telescope RWA for high-angular-momentum applications. Characteristic data for each reaction wheel are given in table 3.

The computer code used to support this analysis was the Space Systems Integrated Simulation (SPASIS, ref. 7) and was modified for this study. SPASIS is a six-degree-of-freedom (DOF), rigid-body simulation program for analyzing orbiting spacecraft. The spacecraft mass and geometry must be user defined, and for this purpose, the spacecraft was modeled using the SDRC I-DEAS computer-aided design and engineering system (ref. 8). SPASIS has the ability to simulate the spacecraft in orbit and calculate environmental effects (forces and moments on the spacecraft) and control system responses. Many other spacecraft-related dynamics may be simulated, including articulation, plume impingement, and docking. The simulation can run single- or multiple-orbit trajectories and outputs the resulting data in tabular or graphic form.

SPASIS contains a fourth-order Runge-Kutta-Gill integrator that integrates the translational and rotational equations of motion, the body orientation quaternion, and the environmental torque components. The program simulates the spacecraft response to environmental effects for every time step to determine spacecraft inertial position and attitude. A time step of 5 sec is the default value. Any value can be input; however, anything much larger than 5 sec can result in a loss of accuracy. A time step of 5 sec provided the best simulation, resulting in both quick turnaround and accuracy.

Also placed within the integration loop are four optional models of control system devices. A reaction control system (RCS) using three models (propulsive jets, control moment gyros (CMGs), and a magnetic torquer) was already included in SPASIS. Langley Research Center added an RWA to the program as the fourth control device option. Four environmental disturbances are simulated: aerodynamic effects (calculated with the 1985 Jacchia atmospheric density model), solar radiation effects, gravity gradient torques, and Earth's magnetic field effects. However, at the geosynchronous operational altitude of the platform, solar radiation is the dominant disturbance, with gravity gradient being secondary.

Solar panels, radiators, and solar dynamic collectors may be modeled in SPASIS as articulating areas. Solar panels and collectors are modeled as Sun tracking devices, while radiators are anti-Sun tracking. When the spacecraft is in the occulted region of the orbit, all devices may be feathered to reduce drag on the spacecraft if desired. In order to keep onboard induced disturbances to a minimum, and with the absence of an atmosphere at geosynchronous orbit, solar panels were not feathered for this analysis.

SPASIS is generally run interactively (but may also be run in a batch mode) on any DEC VAX[1] computer supporting a FORTRAN environment. A plot package that uses DI3000[2] software is available and will plot any of the available program variables versus time.

The following assumptions were made to simplify these analyses: (1) the reaction wheels are placed on the body axes of the spacecraft at the center of mass, (2) the reaction wheels have negligible mass in comparison with the spacecraft, (3) the attitude sensors measure perfect spacecraft alignment with local vertical and local horizontal, (4) the control thrusters fire over the entire numerical integration interval, (5) the thrusters respond instantaneously to control inputs, (6) the reaction wheels have an efficiency of 70 percent (user defined), (7) the reaction wheels can provide their maximum torque at all wheel speeds up to their 70-percent efficiency rating, (8) the structural flexibility of the platform is not considered, and (9) the sensors are perfect.

As previously mentioned, two types of reaction wheels were modelled based on their angular momentum applications. Additionally, two types of commanded torque gains were used. The first, denoted as "small gains," are the gains designed to meet the pointing requirements. The second, denoted as "tight gains," not only meet the pointing requirements but also further reduce the maximum attitude error. The gain values define the control authority of the commanded torque to the movement of the spacecraft. The larger the gains, the more responsive the control system is to the spacecraft position and angular rates.

The small gains come directly from calculations based on the spacecraft equations of motion and the simple proportional-plus-derivative feedback control law. The tight gains were initially calculated in the same manner with a tighter pointing accuracy assumed, and then it was modified by trial and error until the desired results were obtained. The trial and error method was necessary because of uncertainties involved in the approximation technique for determining disturbance magnitudes and the simple model used to represent the spacecraft.

As gain values increase, so does the bandwidth of amplified signals. This means that the control system is more sensitive to error inputs (i.e., quicker response and higher commanded torque). But, at the same time, any sensor and actuator errors are

[1] DEC VAX: A trade name of Digital Equipment Corp.

[2] DI3000: A trade name of Precision Visuals Incorporated.

also magnified to the same degree as any disturbance. This study assumed perfect sensors; therefore, the error within the sensors was not amplified, which could greatly affect attitude control. In addition, it was assumed that reaction wheels could respond with the desired control torque instantaneously. In actual implementation, however, a time lag exists before the torque input is applied (depending on the reaction wheel assembly), and the available torque varies with reaction wheel speed at the time of the torque application. Another trade-off with the use of higher gains is the requirement of using higher frequency (i.e., more expensive) control electronics to provide accurate control at the higher bandwidths.

A concern with flexible spacecraft (see assumption 8) is the excitation of the flexible modes through the control system, or "control spillover." Amplification of the higher frequencies associated with raising the bandwidths could easily excite the flexible modes of the spacecraft (especially with the size and dimensions of the subject platform). Attempting to control the spacecraft to such high accuracies using higher gains to amplify the attitude error could produce an unstable platform because of this excitation not accounted for in this study.

Therefore, electing to achieve an extremely high pointing accuracy by implementing large-magnitude gain values raises costs because of the requirements of extremely accurate sensors, actuators, and a set of advanced, high-speed electronics to drive the system. Additionally, the necessary hardware required to damp out any excitation of the flexible modes increases weight, complexity, and cost. Further study is necessary to better compare these trade-offs.

The equations used for the gain calculations and the control system block diagram are shown in figure 4. The gain values used for the analyses are listed in table 4. This control law was implemented with no modifications to the release version of SPASIS.

The basis for selection of the control device (NASA Standard or Space Telescope RWA) is the desaturation requirements. Reaction wheels become saturated when the wheels reach their maximum design speed and thus can no longer produce required torques for attitude maintenance. When this occurs, the wheels must be desaturated (i.e., despun) in order to regain their effectiveness as angular momentum control devices. The mission profile of the platform dictates that housekeeping activities (i.e., stationkeeping, orbit maintenance, and RWA desaturations) occur no more than twice per 24-hour period (one orbit at geosynchronous altitude). Any more than this would be too disruptive to the pointing accuracy of onboard science instruments. Therefore, in addition to meeting the pointing accuracy requirement of 18 arcsec, the RWA must also be limited to two or less desaturation periods per day.

Results

Figures 5 to 18 present the results of the analysis. Figure 5 shows total environmental torque as measured for a stable platform as a function of orbit time (approximately one 24-hour orbit) for the platform. Figures 6 and 7 show the individual environmental components of solar pressure and gravity gradient torques as being the major sources of outside disturbances. The results of the simulation of the uncontrolled, open-loop system are shown in figure 8 for attitude error as a function of time for one orbit. Here the attitude error, presented as deviation from local vertical–local horizontal, varies between $\pm 90^\circ$ for the pitch axis, while the attitude error varies between $\pm 180^\circ$ for the roll and yaw axes. This indicates that the platform exhibits instability or tumbling.

Figures 9 and 10 show attitude error for the controlled spacecraft (i.e., closed-loop system) over a one-orbit period for the NASA Standard and the Space Telescope RWA's, respectively, using small gains. The NASA Standard RWA's meet the pointing requirement along all three axes (17.6 arcsec in pitch, 12.6 arcsec in roll, and 0.4 arcsec in yaw). The small spikes shown for the pitch axis indicate periods of desaturation. It is clear that the NASA Standard RWA's exceed the desaturation limit of two per orbit. Thruster size for desaturation was determined through a trial and error process intended to yield the least amount of movement along the pitch axis during desaturation. Table 5 shows the RCS jet characteristics used for this analysis, while figure 16 shows the reaction wheel speeds for the NASA Standard RWA's for one orbit. The sharp spikes indicate periods of desaturation. As previously noted for this case, RWA's are defined to desaturate when the wheels reach 70 percent of their maximum design speed (see assumption 6). The resolution of figure 16 is lower than that of figure 11, which shows approximately one-fourth of an orbit. The higher resolution plot, figure 11, shows that the reaction wheels have a speed of zero after the reaction wheel desaturation procedure is performed. Attitude error spikes in figure 9 correspond to desaturation periods when thrusters are firing, as indicated in the reaction wheel speed plots. Figure 16 shows that the wheel along the pitch axis desaturates almost constantly in trying to maintain the required pointing accuracy, while the wheels along the roll and yaw axes never reach saturation. As shown in figure 10, the Space

Telescope reaction wheels meet the pointing requirements along each axis, with the maximum pointing error being about 15.1 arcsec along the pitch axis. Figure 12 shows that the Space Telescope wheels never saturate (in a one-orbit period), as exhibited by the smooth curve along the pitch axis and almost zero wheel speed along the other two axes. In fact, the Space Telescope reaction wheels do not reach saturation for at least 2 days, as indicated in figure 13.

Figures 14 and 15 show the attitude error for the NASA Standard and for the Space Telescope RWA's using tight gains. The NASA Standard RWA's meet the pointing requirement, with a maximum error of 1.6 arcsec along the pitch axis. However, figure 16 shows the numerous desaturation periods needed to maintain this maximum error of 1.6 arcsec. The Space Telescope RWA's also meet the pointing requirement along the pitch axis. Figure 17 again shows that the Space Telescope RWA's do not reach saturation over the span of one orbit and in fact will not saturate for at least 2 days (fig. 18).

Reaction control system (RCS) jets, used for reaction wheel desaturation, are an important device for platform control maintenance. One factor in determining the lifetime of a spacecraft is the amount of propellant it carries onboard. A spacecraft that has reaction wheels that need to desaturate frequently will deplete the available spacecraft propellant more quickly than one whose reaction wheels desaturate very infrequently. This frequent desaturation thus reduces overall spacecraft lifetime. As expected, the NASA Standard RWA's require the most propellant since they need to desaturate the most frequently. In contrast, the Space Telescope RWA's desaturate only once in three orbits. Propellant requirements for the desaturation of the two reaction wheels over an average three orbits for both small and tight gains are shown in table 6.

Conclusions

A rigid-body-pointing analysis was conducted for a proposed Earth science geostationary platform. The analyses performed have demonstrated that the platform can theoretically be controlled to the stringent pointing requirement of 18 arcsec on each axis, subject to certain assumptions. The Hubble Space Telescope reaction wheels provide the highest degree of pointing accuracy of the two reaction wheels investigated. Furthermore, because of the high-angular-momentum storage capacity of the Space Telescope reaction wheels, desaturation is not necessary for at least 2 days in orbit. Fewer desaturation events translate to a lower propellant requirement, but more importantly, fewer desaturations equate to fewer disruptions in pointing accuracy. (More than two desaturations per day would be in violation of mission guidelines.) The other reaction wheel assembly, the NASA Standard, requires very frequent desaturations and therefore violates the two-per-day desaturation limitation. The small gains calculated for the Space Telescope reaction wheels provide a pointing accuracy of 17.6 arcsec to the platform, thereby meeting the accuracy requirement of 18 arcsec. However, the tight gains result in an improved level of pointing accuracy. Further study is necessary to determine the feasibility of implementing the tight gains with the truss structure as a flexible body and without a major increase in cost, should this be deemed valuable to the Mission to Planet Earth initiative.

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References

1. Ride, Sally K.: *Leadership and America's Future in Space—A Report to the Administrator.* NASA, Aug. 1987.

2. Farmer, Jeffery T.; Wahls, Deborah M.; and Wright, Robert L.: *Thermal-Distortion Analysis of an Antenna Strongback for Geostationary High-Frequency Microwave Applications.* NASA TP-3016, 1990.

3. Wahls, Deborah M.; Farmer, Jeffery T.; and Sleight, David W.: *On-Orbit Structural Dynamic Performance of a 15-Meter Microwave Radiometer Antenna.* NASA TP-3041, 1990.

4. Pidgeon, David Joseph: A Subsystem Design Study of an Earth Sciences Geostationary Platform. M.S. Thesis, George Washington Univ., July 1989.

5. Garrison, James L.; and Rowell, Lawrence F.: *Launch Vehicle Integration Options for a Large Earth Sciences Geostationary Platform Concept.* NASA TP-3083, 1991.

6. *Momentum Wheel and Reaction Wheel Assemblies.* S61-1720-05-01, Honeywell, Inc., May 1988.

7. Plowman, Catherine M.: *SPASIS, Version 7.0—User's Guide (Volume I).* LESC-26776 (Contract NAS9-17900), Lockheed Engineering & Sciences Co., Mar. 1989.

8. *I-DEAS™ Level 4—Geomod®. Solid Modeling and Design, User's Guide.* Structural Dynamics Research Corp., c.1988.

Table 1. Payload Pointing Requirements

Payload instrument	Pointing accuracy, arcsec
High-frequency PMR	36.0
IR vertical sounder	1.1
High-resolution imager	18.0
Michelson sounder	18.0
Fabry-Perot sounder	18.0
Lightning mapper	180.0
Ozone mapper	18.0
Active cavity radiometer	360.0
Earth radiation radiometer	29.0
Solar disk sextant	360.0
X-ray imager	360.0
Multi-spectral imager	1.1
Laser ranger	1.1
Coherent radar	3.6
Solar spectrometer	360.0
Low-frequency PMR (15 m)	36.0
Space environment monitor	360.0
Data collection platform	360.0

Table 2. Platform Mass and Inertia Properties

Mass, kg	6569
Moments of inertia, kg-m^2:	
I_{xx}	1.967×10^5
I_{yy}	5.217×10^5
I_{zz}	4.200×10^5
I_{xy}	1.383×10^3
I_{yz}	3.243×10^3
I_{zx}	8.077×10^4

Table 3. Characteristics of Reaction Wheels and Single-Gimbal Control Moment Gyros

Characteristic	NASA Standard	Space Telescope
Angular momentum, N-m-sec	20.001	264.420
Wheel speed, rad/sec	226.195	314.159
Mass, kg	9.072	47.628
Maximum power, W	<150	<400
Output torque, N-m	0.2966	0.8051

Characteristic	Low torque CMG	Midrange torque CMG
Angular momentum, N-m-sec	305.04	813.45
Mass, kg	52.16	63.50
Maximum power, W	<50	<50
Output torque, N-m	305.04	305.04

Table 4. Gain Values

	Values for—	
	Small gains	Tight gains
K_{Ax}	−0.467	−100.000
K_{Ay}	−76.000	−650.000
K_{Az}	−2.339	−8.000
K_{Rx}	−473.070	−6 917.370
K_{Ry}	−10 215.664	−29 874.700
K_{Rz}	−1 512.398	−3 959.980

Table 5. RCS Jet Characteristics

[$I_{sp} = 230$ sec]

Axis	Thrust level, N, for—	
	Small gains	Tight gains
Yaw	3.179×10^{-4}	3.179×10^{-4}
Pitch	11.751×10^{-4}	11.751×10^{-4}
Roll	11.751×10^{-4}	11.751×10^{-4}

Table 6. Propellant Requirements for Three Orbits

RWA type	Mass of propellant, kg, using—	
	Small gains	Tight gains
NASA Standard	0.06291	0.06228
Space Telescope	.02356	.02356

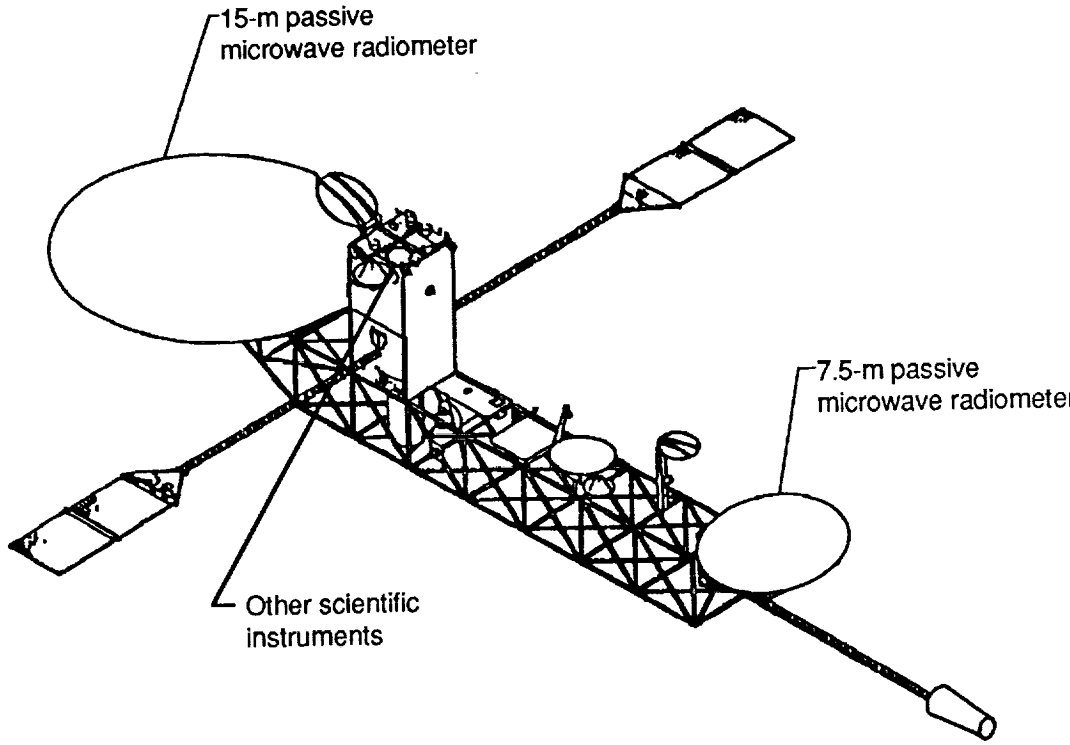


Figure 1. Ford Earth Observation Science Platform Configuration.

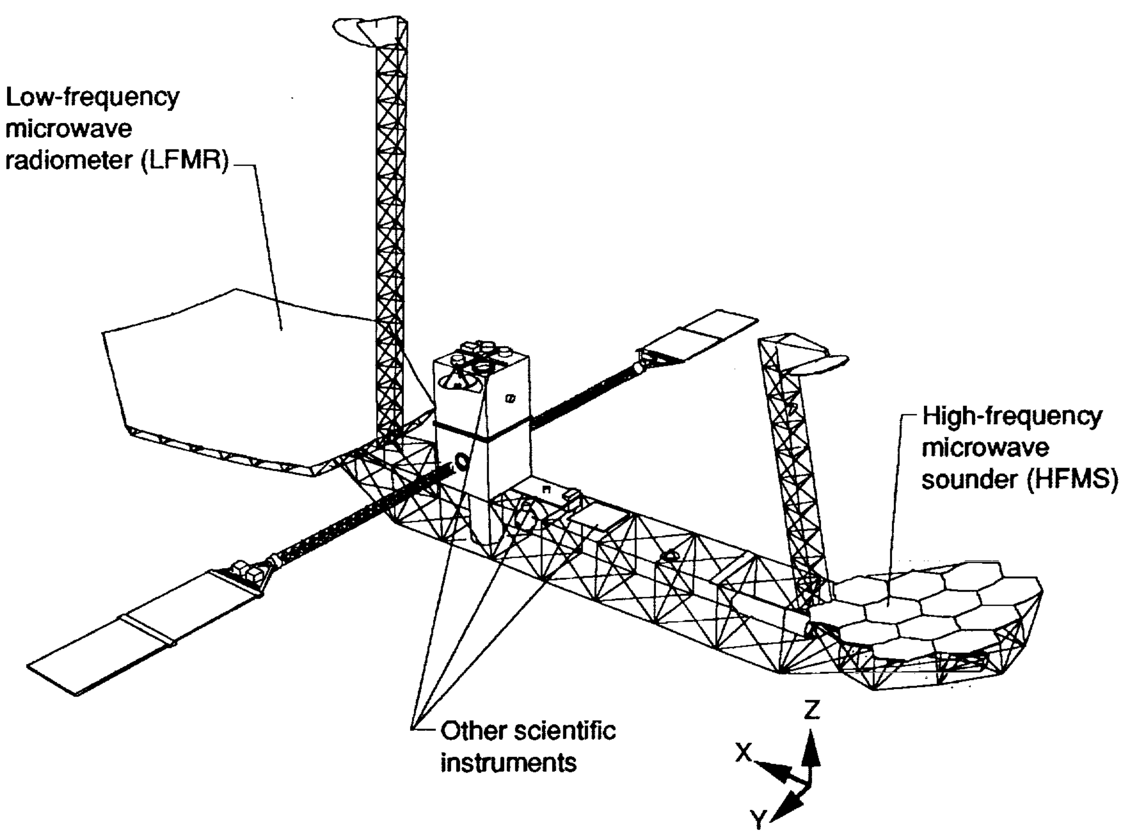


Figure 2. LaRC Geostationary Earth Science Platform configuration.

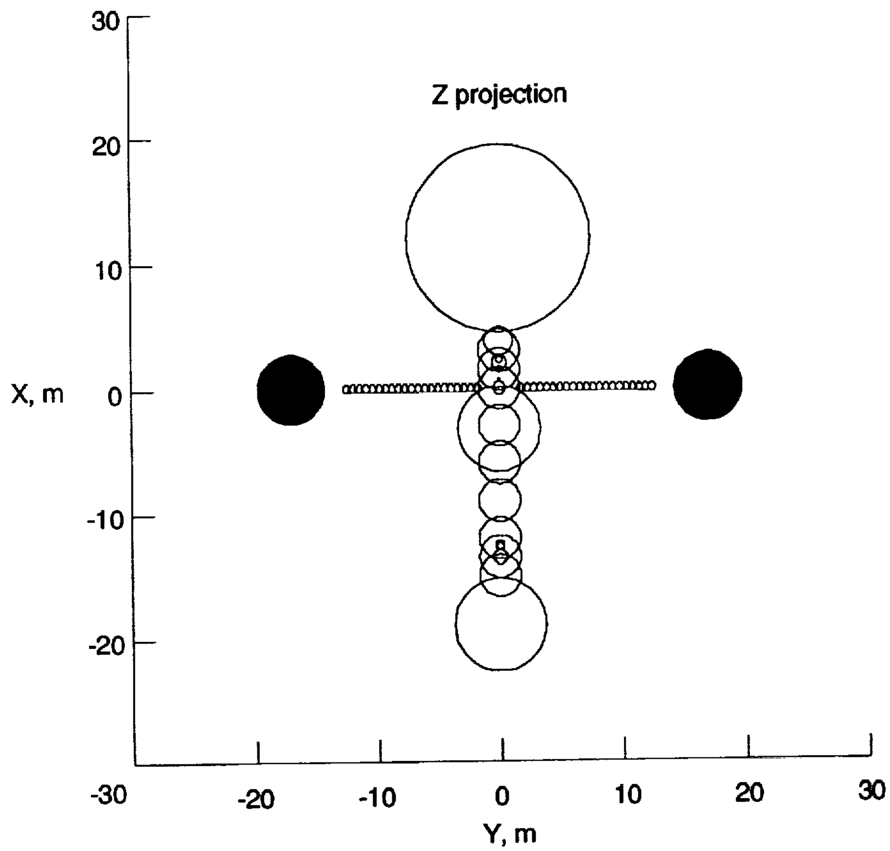


Figure 3. Simplified equivalent mass, area, and inertia analysis model.

Gain Equations

$$\omega^2 = \frac{T_{max}}{eI}$$

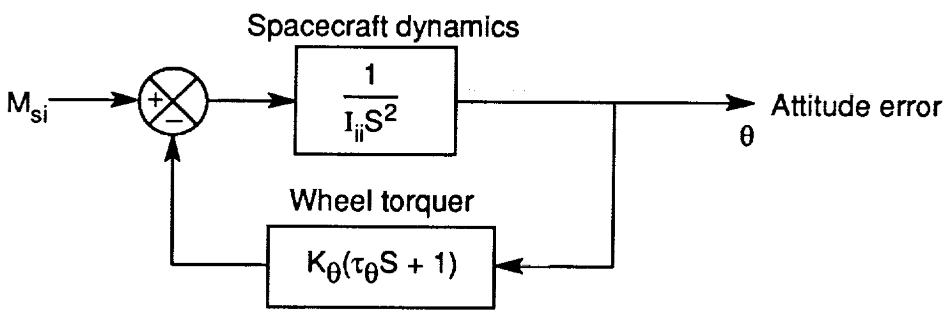
$$K_A = I\omega^2$$

$$K_R = 2I\omega^2$$

where

T_{max}	assumed maximum torque value of RWA, N-m
e	maximum allowed error, rad
I	principal moment of inertia, kg-m^2

Control System Block Diagram Per Axis



where

M_{si}	disturbance torques	i	= 1, 2, and 3 (roll, pitch, and yaw axes, respectively)
I	moment of inertia		
K_θ	proportional gain K_A	θ	attitude error
$K_\theta\tau_\theta$	rate gain K_R	S	Laplace variable
		τ_θ	applied torque

Figure 4. Gain equations and control system block diagram.

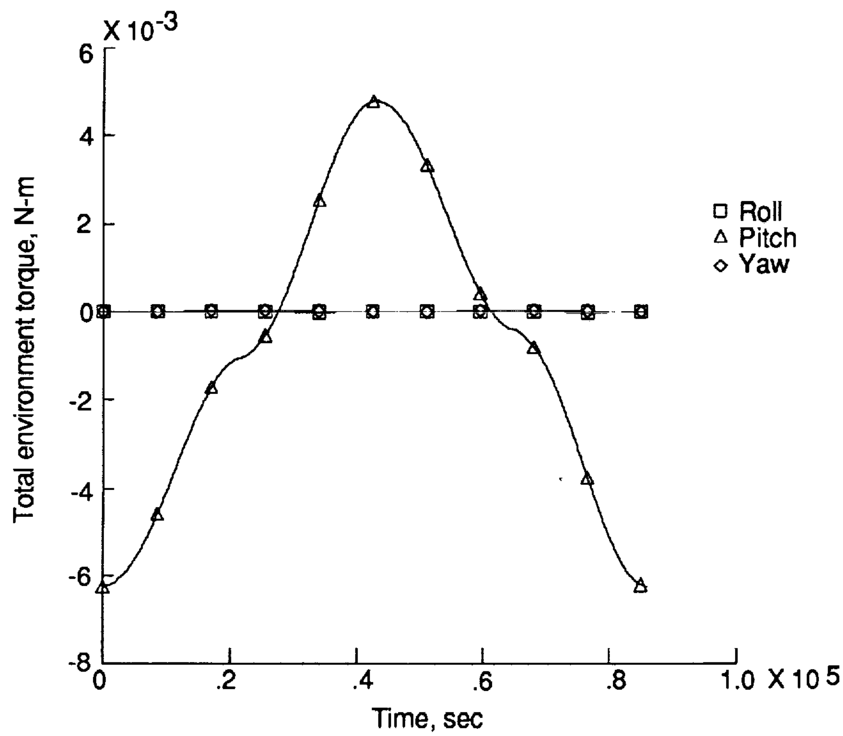


Figure 5. Total environmental torque on platform for one 24-hour orbit.

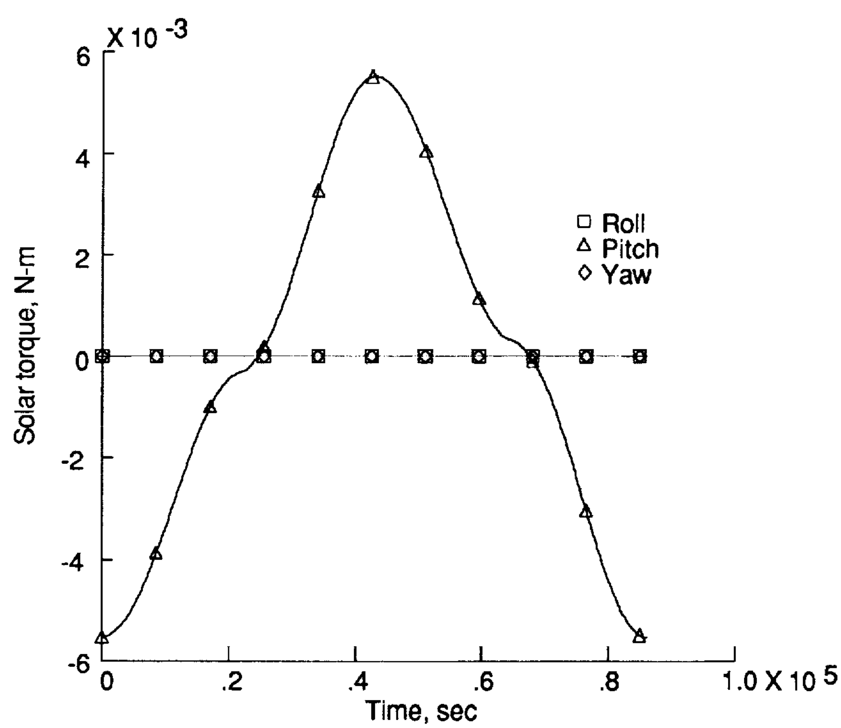


Figure 6. Solar pressure torque for one 24-hour orbit.

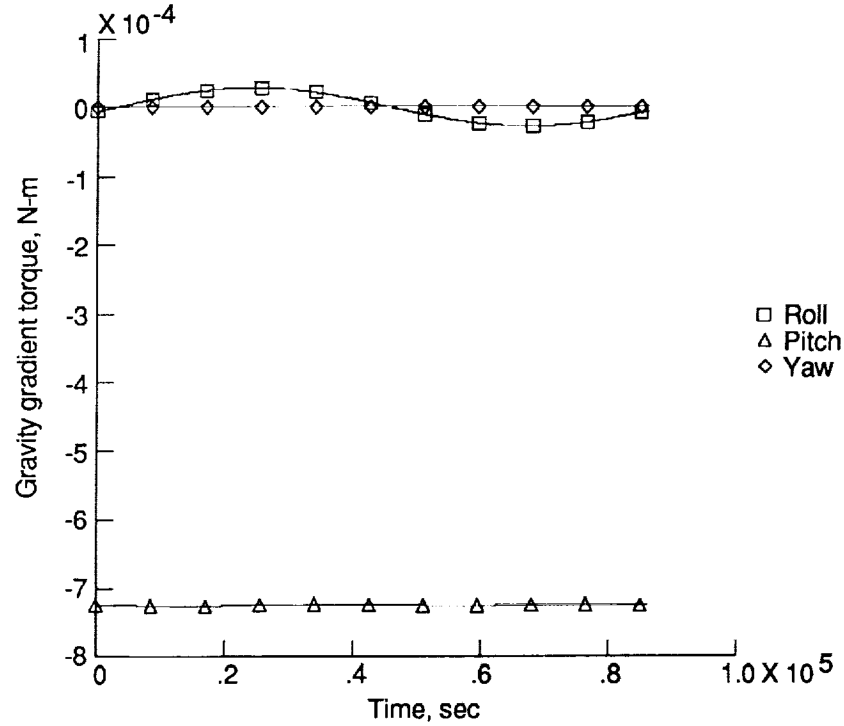


Figure 7. Gravity gradient torque for one 24-hour orbit.

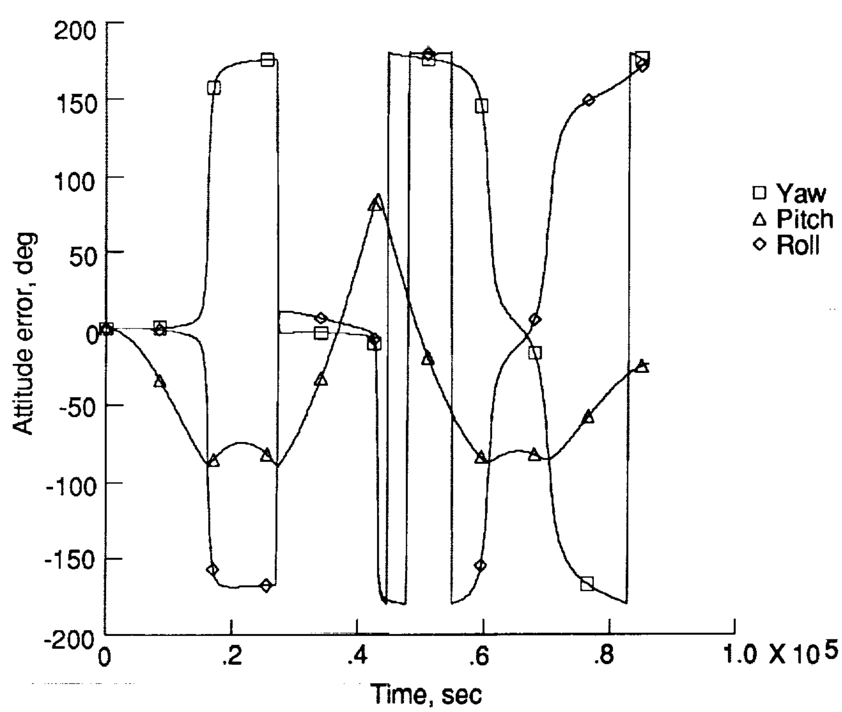


Figure 8. Attitude error of uncontrolled platform for one 24-hour orbit.

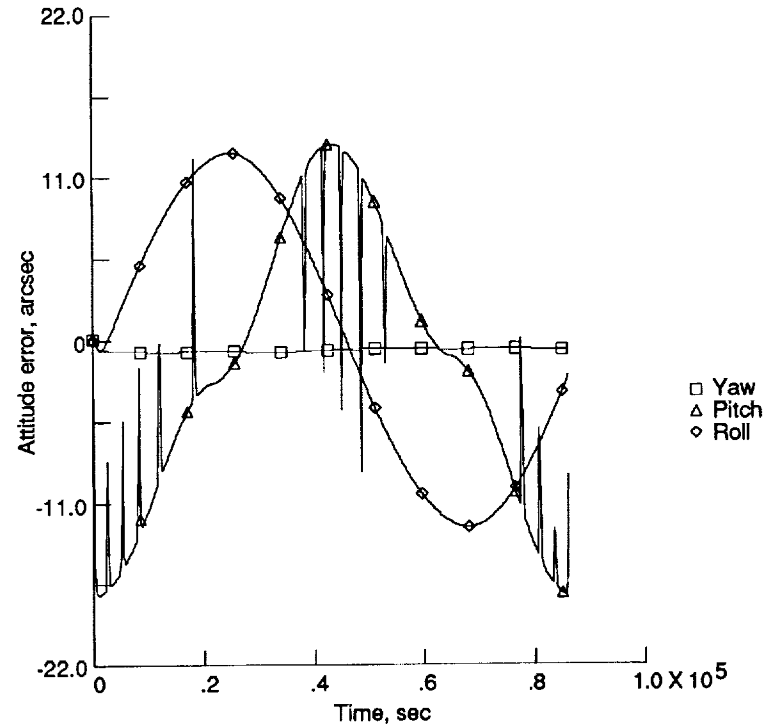


Figure 9. Attitude error for NASA Standard RWA's using small gains for one 24-hour orbit.

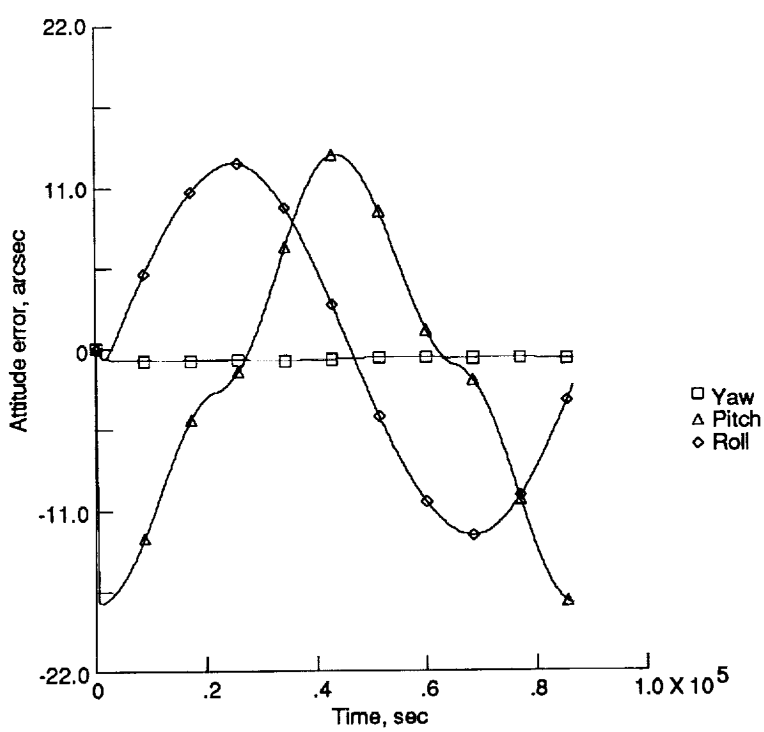


Figure 10. Attitude error for Space Telescope RWA's using small gains for one 24-hour orbit.

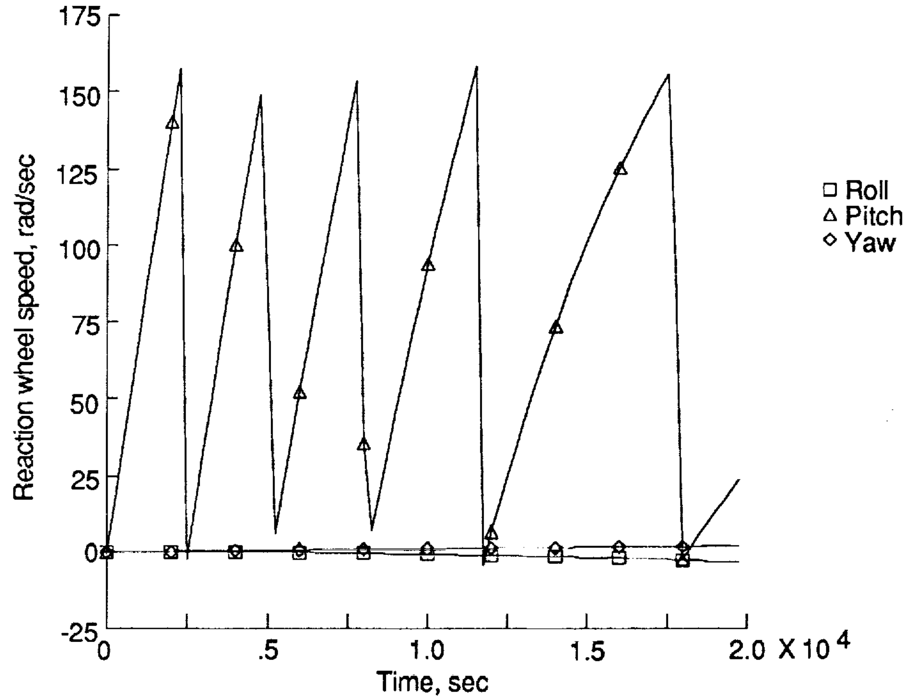


Figure 11. Reaction wheel speed for NASA Standard RWA's using small gains for one-fourth orbit.

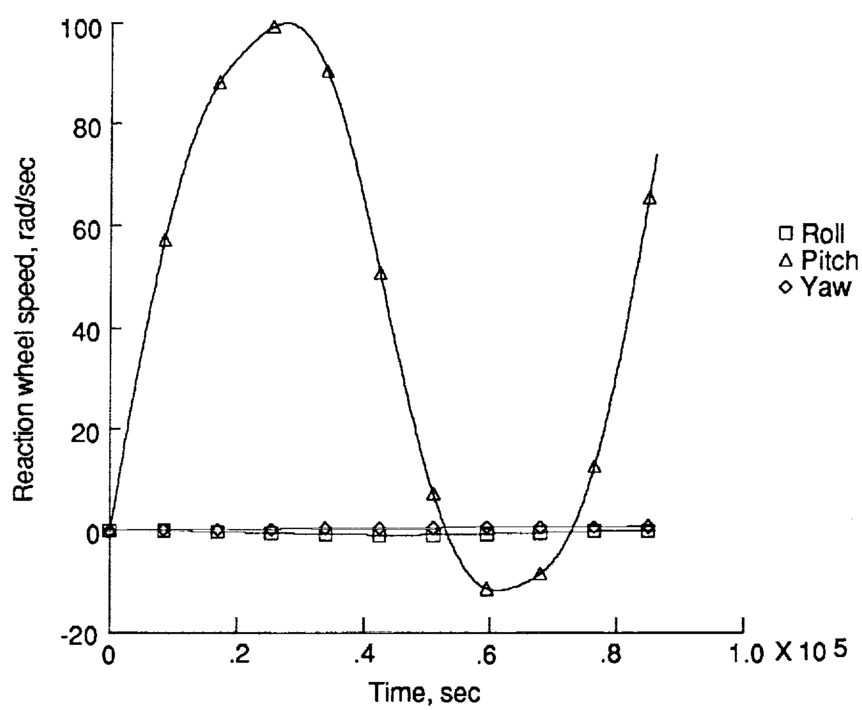


Figure 12. Reaction wheel speed for Space Telescope RWA's using small gains for one 24-hour orbit.

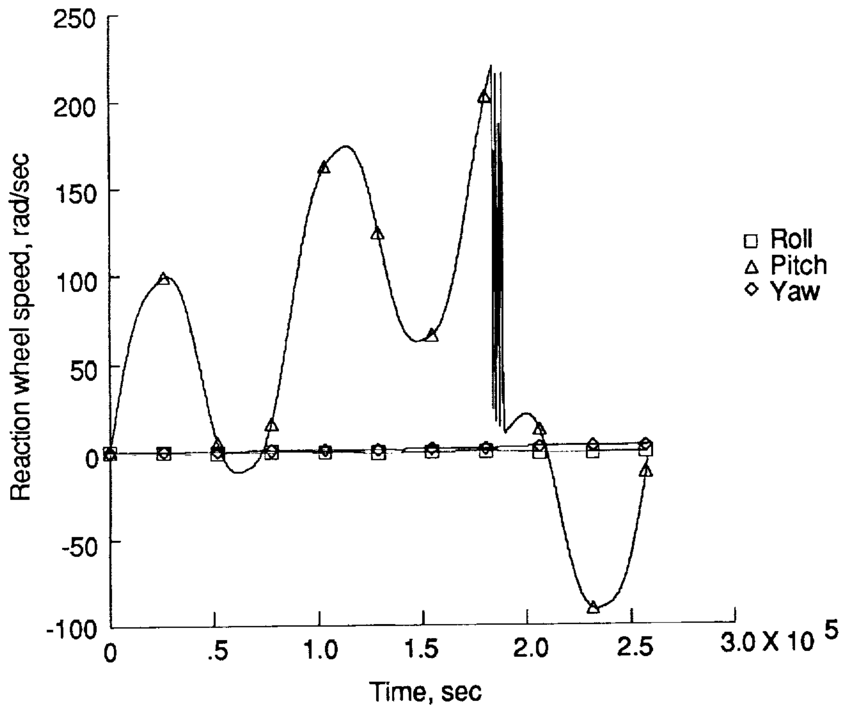


Figure 13. Reaction wheel speed for Space Telescope RWA's using small gains for three 24-hour orbits.

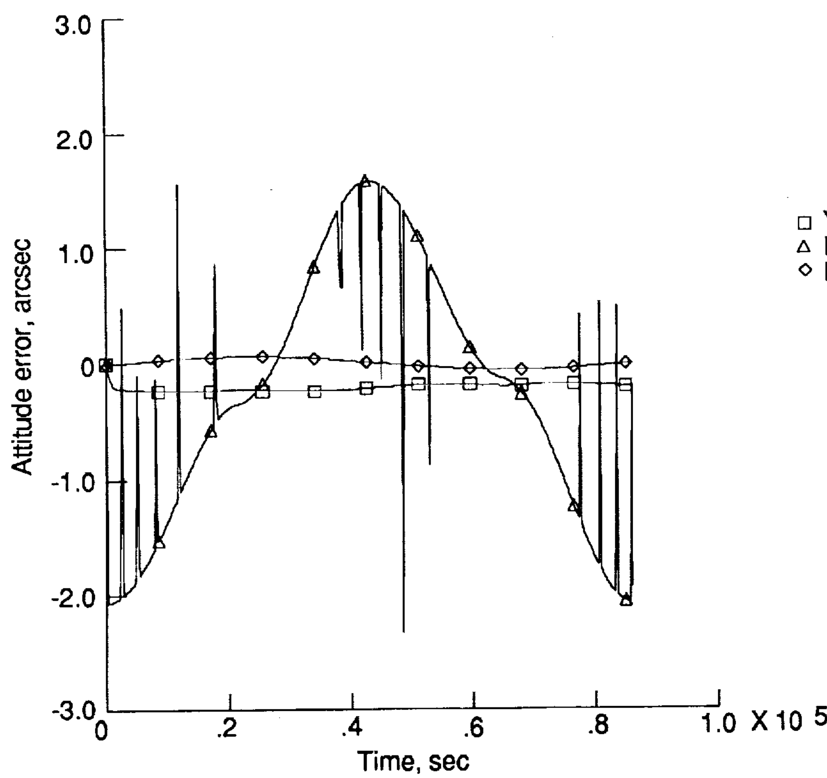


Figure 14. Attitude error for NASA Standard RWA's using tight gains for one 24-hour orbit.

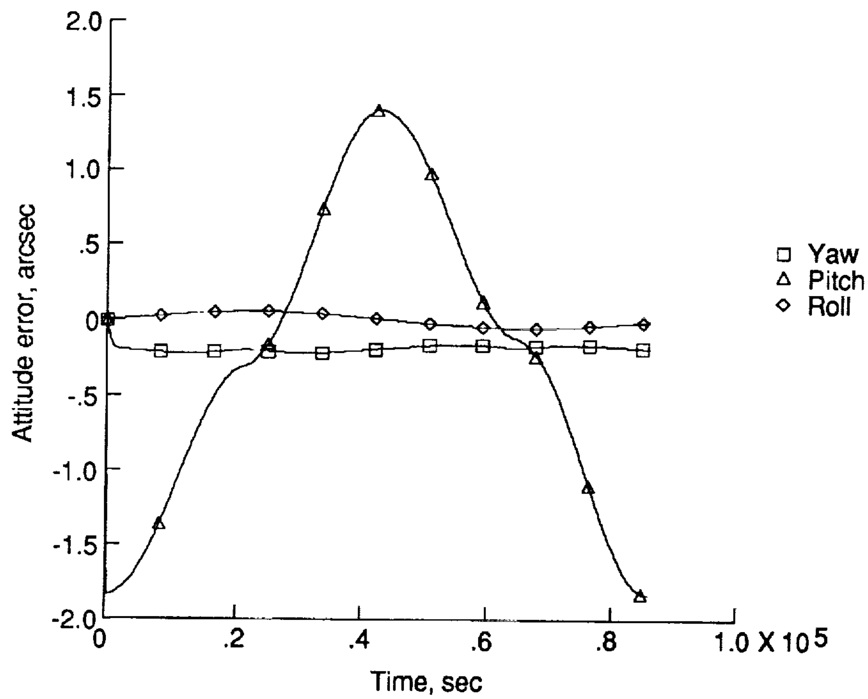


Figure 15. Attitude error for Space Telescope RWA's using tight gains for one 24-hour orbit.

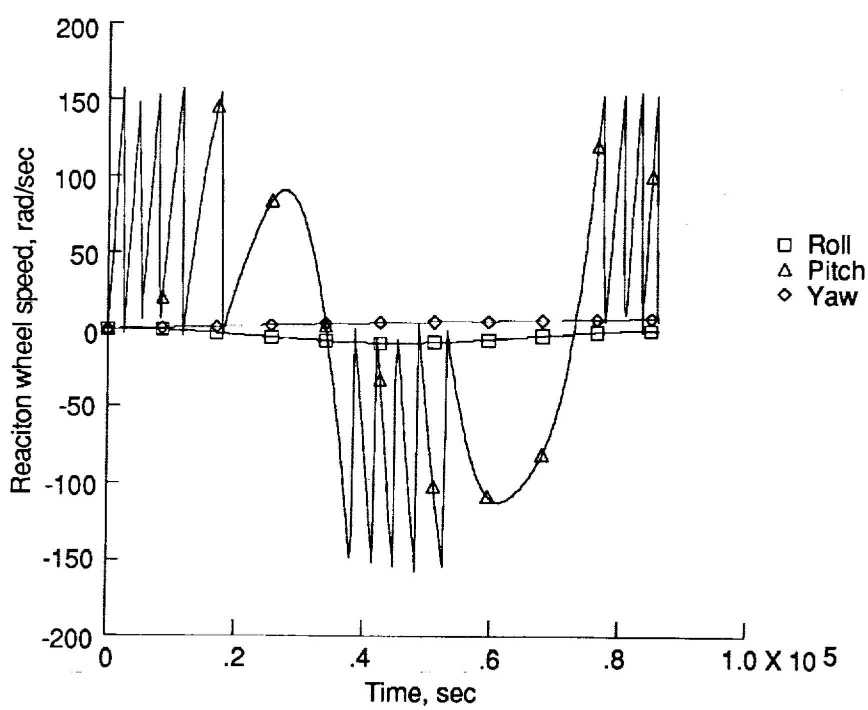


Figure 16. Reaction wheel speed for NASA Standard RWA's using tight gains for one 24-hour orbit.

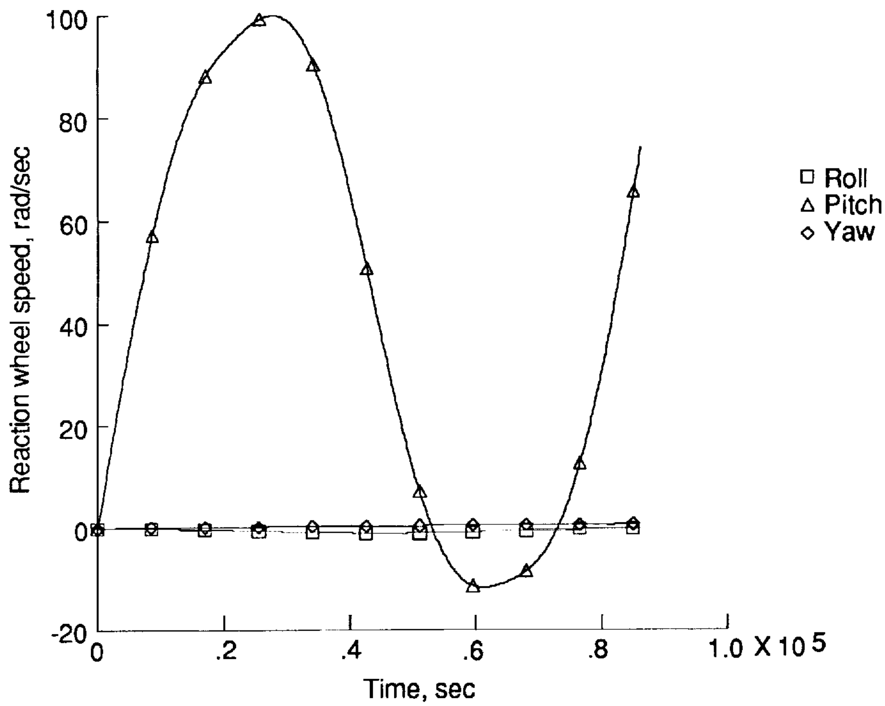


Figure 17. Reaction wheel speed for Space Telescope RWA's using tight gains for one 24-hour orbit.

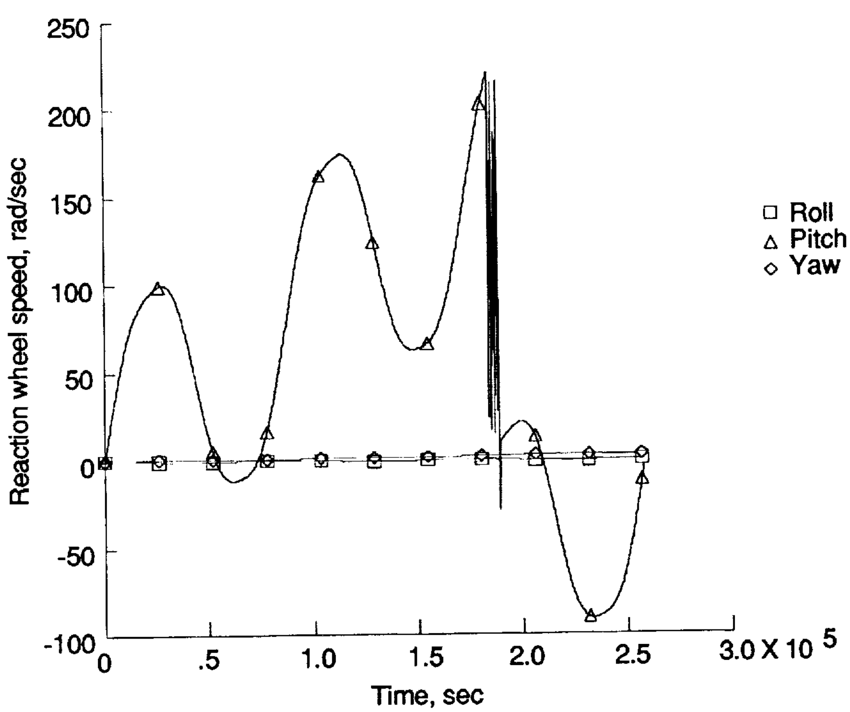


Figure 18. Reaction wheel speed for Space Telescope RWA's using tight gains for three 24-hour orbits.

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15. Supplementary Notes

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16. Abstract

The Mission to Planet Earth program envisions both low Earth and geostationary orbiting spacecraft supporting instruments to measure and monitor land, ocean, and atmospheric variables that are important to understanding Earth's global change mechanisms. To minimize the number of spacecraft required in geostationary orbit, large, multipurpose platforms have been proposed to carry many high-resolution science instruments and sensors. Several of these instruments are large antennas that tend to accentuate the environmental- and spacecraft-induced disturbances, thereby affecting spacecraft controllability. An analysis of rigid-body pointing was conducted to determine if the subject spacecraft could maintain pointing to within a very precise 18 arcsec (0.005°) measured at the rigid payload module. The NASA Standard and the Hubble Space Telescope reaction wheel assemblies were investigated as attitude control devices. Results indicate that the spacecraft can theoretically be controlled to maintain 18 arcsec along each axis. The Space Telescope reaction wheel assembly provides the highest degree of pointing accuracy along with the lowest propellant requirement for wheel desaturation, although with a slight increase in mass and power requirements. The reaction wheels investigated are all representative of currently available technology.

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